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**W-8000 München 80 (DE)**(54) **Tungsten-imido catalysts for ring-opening metathesis polymerization of cycloolefins.**

(57) This invention relates to a two component catalyst system for the polymerization of metathesis polymerizable polycyclic cycloolefins, comprising (a) a tungsten-imido compound having the formula  $W(NR^1)_xX_{4-x}(OR^2)_y \cdot L_y$  wherein  $x=0, 1, 2, 3$  or  $4$ ;  $y=0$  or  $1$ ;  $R^1$  and  $R^2$  are alkyl, phenyl, phenyl-substituted phenyl, phenylalkyl or halogen-substituted derivatives of alkyl, phenyl, phenyl-substituted phenyl or phenylalkyl;  $X=Br$  or  $Cl$ ; where alkyl has 1 to 8 carbon atoms, phenyl substituted phenyl has 12-18 carbon atoms and phenylalkyl has 7 to 20 carbon atoms; and  $L$  is a donor ligand; and (b) an activator compound.

The catalyst system is used to prepare thermoset molded articles having low levels of residual monomer.

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This invention relates to a catalyst system for the ring-opening metathesis polymerization of polycyclic cycloolefins, especially dicyclopentadiene.

Recent publications have disclosed that tungsten and molybdenum imido-alkylidene complexes, e.g.,  $M(NAr)(CHR)(OR)_2$  ( $M = Mo$  or  $W$ ), can be used for ring-opening metathesis catalysis resulting in the preparation of linear polymers and polyacetylenes. In these cases, the  $M(NAr)(CHR)(OR)_2$  species are regarded as very active unicomponent catalysts. Schrock et al. in J. Am. Chem. Soc. 110, 1423 (1988) describe a number of tungsten complexes of the stoichiometry  $W(OR')_2(=CHR'')(NAr')$ , where  $OR'$  is selected from alkoxide (e.g.,  $OCMe_3$ ), thiophenylalkyl (e.g.,  $SC_6H_3-2,6-i-Pr_2$ ), phenoxide (e.g.,  $OC_6H_3-2,6-i-Pr_2$ ) fluoroalkoxide (e.g.,  $OC(CF_3)_3$ ), and  $Ar'$  is a substituted aromatic ring, such as 2,6-diisopropylphenyl or 2,6-dimethylphenyl. A number of methods have been previously disclosed for the preparation of tungsten-imido-alkylidene complexes. However, all of these methods provided for separate preparation of such alkylidene complexes prior to addition to the monomer. For example, the original preparation of  $W(CHR)(CH_3)_3(NAr)(OC(CH_3)_3)_2$  (where  $Ar = 2,6$ -diisopropylphenyl) was achieved by reacting  $W(CHR)(CH_3)_3(NAr)(dme)Cl_2$  (where  $dme$  is dimethoxyethane) with two equivalents of lithium *tert*-butoxide. The  $W(CHR)(CH_3)_3(NAr)(dme)Cl_2$  was prepared by a five step reaction as described by Schaverian et al. in the Journal of the American Chemical Society, 1986, 108, 2771-2773.

The previous complexes have not been used for polymer synthesis where a two (or more) component system, such as in reaction injection molding (RIM), is used.

The catalyst composition of this invention for the polymerization of at least one strained ring nonconjugated polycyclic cycloolefin monomer and comprising a tungsten compound and an activator is characterized in that the tungsten compound is a tungsten-imido compound having the formula  $W(NR^1)_x(NR^2)_y(OR^3)_z \cdot L_y$  wherein  $x = 0, 1, 2, 3$  or  $4$ ;  $y = 0$  or  $1$ ;  $R^1$  and  $R^2$  are selected from alkyl, phenyl, phenyl-substituted phenyl, phenylalkyl or halogen-substituted derivatives of alkyl, phenyl, phenyl-substituted phenyl or phenylalkyl groups;  $X = Br$  or  $Cl$  and  $L$  is a donor ligand; said alkyl groups contain 1 to 8 carbon atoms; said phenyl-substituted phenyl groups contain 12 to 18 carbon atoms and said phenylalkyl groups contain 7 to 20 carbon atoms.

The tungsten-imido alkylidenes of this invention can be prepared *in situ* to provide a catalyst composition that polymerizes strained ring polycyclic cycloolefins to very low levels of residual monomer.

Metathesis polymerizable strained ring nonconjugated polycyclic cycloolefins such as dicyclopentadiene (DCPD), trimers of cyclopentadiene, higher order cyclopentadiene oligomers, norbornene, norbornadiene, 4-alkylidene norbornenes, dimethanohexahydronaphthalene, dimethanooctahydronaphthalene, and alkyl-substituted derivatives of said cycloolefins and mixtures thereof can be polymerized to high polymer yield in bulk by employing the tungsten-imido compounds of the invention. These tungsten-imido compounds can also be employed in the solution polymerization of strained cycloolefins. The preferred cyclic monomer is dicyclopentadiene (DCPD) or a mixture of dicyclopentadiene with other strained ring hydrocarbons in ratios of 1 to 99 mole % of either monomer, preferably 75 to 99 mole % dicyclopentadiene.

Typical examples of alkyl groups employed in the tungsten-imido compounds of this invention are methyl, ethyl, isopropyl, hexyl, *tert*-butyl and *tert*-octyl groups. Typical examples of phenyl-substituted phenyl groups are 2,6-diphenylphenylene and 2-phenylphenylene groups. Typical examples of phenylalkyl groups are tolyl, benzyl, triphenylmethyl, 2,6-diheptylphenyl, 2,6-diisopropylphenyl, 2,4,6-trimethylphenyl and 2,6-di-*tert*-butylphenyl groups. Typical examples of halogen-substituted derivatives of alkyl groups are trifluoro-*tert*-butyl (i.e.  $(CF_3)(CH_3)_2C$ ), hexabromo-*tert*-butyl (i.e.  $(CBr_3)_2(CH_3)C$ ), perfluoro-*tert*-butyl, trichloromethyl and hexachloroisopropyl (i.e.  $(CCl_3)_2C$ ). Typical examples of halogen-substituted phenyl groups are pentafluorophenyl, 2,6-dichlorophenyl, 2,6-dibromophenyl and 4-iodophenyl groups. Typical examples of halogen-substituted phenyl-substituted phenyl groups are 2,6-di-(6-chlorophenyl)phenylene and 2,6-di-(2,6-difluorophenyl)phenylene. Typical examples of halogen-substituted phenylalkyl groups are bis-trifluoromethyltrifluoromethyltolyl, 4-chloro-2,6-dimethylphenyl and 2,6-di(tribromomethyl)phenyl. Typical donor ligands are diethyl ether, ethylene glycol dimethyl ether, triethylene glycol dimethyl ether, 2-methoxyethyl ether, tetraethylene glycol dimethyl ether, tetrahydrofuran, acetonitrile, benzonitrile, pyridine, pyrazine and quinuclidine.

The phenyl ring in the above formula can be mono-substituted at the 2, 3, or 4 positions. In the disubstituted phenyl ring the substituents can be at the 2,6; 2,5; 2,4; or 2,3 positions or at the 3,4; 3,5; or 3,6 positions. The substituents can be the same or different groups. In the trisubstituted phenyl ring, substituents can be at the 2,3,4; 2,3,5; 2,3,6; 3,4,5; and 2,4,5 positions, and the substituents can be the same or different groups. The two tetra-substituted structures for the phenyl ring have substituents at the 2,3,4,5 or the 2,3,4,6 positions, where the substituents can be the same or different.

Various activator compounds can be employed to act together with the tungsten-imido compounds described above to cause the polymerization of strained ring polycyclic cycloolefins. Mixtures of two or

more activator compounds may produce more desirable polymerization conditions and more desirable polymer properties than a single activator compound in certain situations. However, a single activator compound is sufficient. Suitable activator compounds that can be employed in the practice of this invention include, for example, trialkylaluminums, dialkylaluminum halides, alkylaluminum dihalides, dialkyl(alkoxy)-aluminums, alkyl(alkoxy)aluminum halides, dialkylzincs, diarylzincs, alkylsilanes ( $\text{RSiH}_3$ ,  $\text{R}_2\text{SiH}_2$ , and  $\text{R}_3\text{SiH}$ ), tetraalkyltins, trialkyltin hydrides, dialkyltin dihydrides, and triaryl tin hydrides. Specific examples of activators include ethylaluminum dichloride, diethylaluminum chloride, triethylaluminum, diethylzinc, dibutylzinc, ethyl-*n*-propoxyaluminum chloride, diphenylzinc, tri-*n*-butyltin hydride, trioctyltin hydride, diphenyltin dihydride, and triphenyltin hydride. The tin activators are preferred. Among the trialkyltin hydrides suitable for use in the process of the invention, tri-*n*-butyltin hydride and trioctyltin hydride are most preferred.

The dicyclopentadiene monomer is preferably of high purity, i.e., containing less than 2% impurities. Other monomers or comonomers employed in the practice of this invention should be about this degree of purity. It is also contemplated, however, that the polymerization feed compositions of this invention can polymerize less pure grades of dicyclopentadiene when the appropriate tungsten catalyst compound, activator compound and other components are employed.

When the two parts of the catalyst system (i.e., the tungsten-imido compound and the activator) are combined, the resulting cycloolefin (for example, DCPD) to tungsten-imido compound ratio will be from 500:1 to 15,000:1 on a molar basis, preferably 2000:1, and the molar ratio of the tungsten-imido compound versus the activator ratio will be from 1:1 to 1:8. Generally, the polymerization takes place in bulk, but the catalyst components can be dissolved in a small amount of solvent, such as toluene. It is preferred, however, to use DCPD as a solvent. When liquid tri-*n*-butyltin hydride is used as the activator compound, no solvent is necessary for the addition since tri-*n*-butyltin hydride is readily soluble in DCPD. A preferred method for the polymerization of DCPD is to contact the tungsten-imido compound stream with the activator component stream, wherein at least one of the streams contains the monomer. For example, it is possible to dissolve the tungsten-imido compound in DCPD and either to dissolve the activator in DCPD or in another solvent or to use the activator without any solvent. Usually both the tungsten-imido compound and the activator are first dissolved in separate streams of DCPD prior to the mixture of the streams. After the streams have contacted with each other the resulting mixture can be poured or injected into a mold, where the polymerization takes place. The polymerization is exothermic, but heating the mold to 50° to 100° C is preferred. The tungsten-imido compound can be stored in DCPD for some time provided that the DCPD contains only a few ppm of water or less. The activator compounds, e.g., trialkyltin hydride, are storable in DCPD for prolonged periods and tolerate relatively higher levels of water than the tungsten-imido compounds without losing their reactivity.

Stabilizers may be necessary when the monomer and tungsten-imido compound are to be stored together for prolonged periods of time, with the monomer and activator combination stored separately. In order to maintain the stability of tungsten compounds in high purity DCPD and aid in their solubility, it has been shown that the addition of stabilizing or solubilizing compounds to the solutions may be necessary. The addition of a stabilizer is not an absolute requirement of the practice of the invention. Typical stabilizer compounds include Lewis bases such as diethyl ether, ethylene glycol dimethyl ether, 2-methoxyethyl ether, triethylene glycol dimethyl ether, tetraethylene glycol dimethyl ether, benzonitrile, acetonitrile, tetrahydrofuran, monophenols such as 2,6-di-*tert*-butyl-4-methylphenol, 2,6-di-*tert*-butyl-4-sec-butylphenol) bisphenols such as 2,2'-methylenebis(4-methyl-6-butylphenol), 2,2'-methylenebis(4-ethyl-6-butylphenol); 4,4'-methylenebis(2,6-di-*tert*-butylphenol); 2,2'-ethylenebis(4,6-di-*tert*-butylphenol); 2,2'-methylenebis(4-ethyl-6-(1-methylenebis(4-ethyl-6-(1-methylcyclohexyl)-phenol); 4,4'-butylidenebis(6-*tert*-butyl-3-methylphenol); 4,4'-thiobis(6-*tert*-butyl-3-methylphenol); 4,4'-methylenebis(2,6-dimethylphenol); 1,1'-thiobis(2-naphthol); 2,2'-thiobis(4-methyl-6-*tert*-butylphenol); 2,2'-isobutylidenebis(4,6-dimethylphenol); 2,2'-methylenebis(4-methyl-6-cyclohexylphenol); polyphenols such as 1,3,5-trimethyl-2,4,6-tris(3,5-di-*tert*-butyl-4-hydroxybenzyl)-benzene; the butylated reaction product of *p*-cresol and dicyclopentadiene. In addition, mixtures of the above stabilizer compounds such as a mixture of 2-methoxyethyl ether and one or more phenols can be employed in the practice of this invention.

A rate moderator can also be added to the tungsten or activator compounds. The rate moderator compound prevents the polymerization process from being too rapid, provides for adequate mixing of the catalyst components, and allows the mold to be completely filled. The rate moderator compounds useful in this invention include the various nitrogen or phosphorus compounds used for this purpose as described in U.S. Patents 4,727,125; 4,883,849, and 4,933,402. Preferred rate moderators include pyridine; pyrazine; tributyl phosphite ( $(\text{BuO})_3\text{P}$ ); triethylphosphine ( $\text{PEt}_3$ ); tributylphosphine ( $\text{PBu}_3$ ); tricyclohexylphosphine ( $\text{PCy}_3$ ); triphenylphosphine ( $\text{PPh}_3$ ); methyldiphenylphosphine ( $\text{PMePh}_2$ ); dimethylphenylphosphine ( $\text{PMe}_2\text{Ph}$ ); triethyl phosphite ( $\text{P}(\text{OEt})_3$ ); triisopropyl phosphite ( $\text{P}(\text{O}-i\text{Pr})_3$ ); ethyldiphenyl phosphonite ( $\text{P}(\text{OEt})_2\text{Ph}$ );

(OEt)Ph<sub>2</sub>); triphenyl phosphite OP(OPh)<sub>3</sub>); triisopropylphosphine (P-i-Pr<sub>3</sub>); trimethyl phosphite (P(OMe)<sub>3</sub>); *tert*-butylphosphine (P-*tert*-Bu<sub>3</sub>); diethylphenyl phosphonite (P(OEt)<sub>2</sub>Ph); and tribenzylphosphine (P(CH<sub>2</sub>Ph)<sub>3</sub>). The stabilizer and rate moderators may not be necessary when lower purity dicyclopentadiene monomer is employed. Various optional components can be present in the reaction mixture during polymerization. Additives such as solvents, elastomers, blowing agents, fillers, pigments, antioxidants, light stabilizers, plasticizers, foaming agents, reinforcing agents, and polymeric modifiers can be added to obtain desired properties. In some embodiments of this invention, a preformed elastomer that is soluble in the reactant streams is added to the metathesis-catalyst system in order to increase the impact strength of the polymer. The elastomer is dissolved in either or both of the reactant streams in an amount from 3 to 15 weight percent range, based on the weight of monomer. Illustrative elastomers include natural rubber, butyl rubber, polyisoprene, polybutadiene, polyisobutylene, ethylene-propylene copolymer, styrene-butadiene-styrene triblock rubber, random styrene-butadiene rubber, styrene-isoprene-styrene triblock rubber, ethylene-propylene-diene terpolymers, ethylene-vinyl acetate and nitrile rubbers. Various polar elastomers can also be employed. The amount of elastomer used is determined by its molecular weight and is limited by the viscosity of the resultant reactant streams. The streams containing elastomer cannot be so viscous that mixing is not possible. Although the elastomer can be dissolved in either one or both of the streams, it is desirable that it be dissolved in both. These components are most conveniently added to the reaction as constituents of one or more of the reaction mixture streams, as liquids or as solutions in the monomer.

In the following examples, some of the tungsten-imido compounds are prepared utilizing tungsten oxytetrachloride (WOCl<sub>4</sub>) obtained commercially. In some preparations the WOCl<sub>4</sub> was prepared by reacting tungsten hexachloride (WCl<sub>6</sub>) with hexamethyldisiloxane (Me<sub>3</sub>SiOSiMe<sub>3</sub>) in the following manner. A solution of hexamethyldisiloxane (HMDS)(10.72 ml, 0.0483 moles) is dissolved in toluene (50 ml) and placed in a glass column fitted with a septum and a stopcock to which a needle is attached. This solution is added dropwise into a toluene (250 ml) solution of WCl<sub>6</sub> (20 grams, 0.0504 mol) while stirring in a 500 ml round bottomed flask. After the addition is completed, the column is removed and the reaction mixture allowed to stir overnight under nitrogen. The brown solution is filtered in the dry box to yield a quantity of crude, orange WOCl<sub>4</sub> (14.6 g; 84% yield). The crude material is sublimed under reduced pressure at 100 °C in three stages to give bright orange crystalline WOCl<sub>4</sub> (13.7 g; yield 79%). In those examples where phenyl isocyanate and 2,6-diisopropylphenyl isocyanate are employed, they are first dried over 4A molecular sieves and purged with nitrogen prior to use. Where used, 2-methoxyethyl ether and/or rate moderators, such as tributyl phosphite are also dried over the appropriate molecular sieves and sparged with dry nitrogen prior to use.

All operations are carried out under a dry nitrogen atmosphere or in vacuum either in a Vacuum Atmospheres Dri-Lab (inerted by argon gas) or other known techniques. All solvent transfers must be performed by cannula or syringe techniques to maintain an inert atmosphere.

In the examples in which polymerization studies are set forth, the following general procedures are followed. All manipulations are performed anaerobically in nitrogen-sparged pop bottles or under an argon atmosphere (Vacuum Atmospheres Dri-Lab) or using other known techniques. Tri-*n*-butyltin hydride (packaged in Sure/Seal bottle) is stored refrigerated (0 °C). Triethylaluminum, (Et<sub>3</sub>Al, 1.9 M in toluene), diethylaluminum chloride (Et<sub>2</sub>AlCl)(1.8 M in toluene), and diethylzinc (Et<sub>2</sub>Zn, 1.1 M in toluene) are used as received. Dicyclopentadiene (DCPD)(98-99%) is used to prepare all tungsten-imido compound and activator polymerization stock solutions. All liquid transfers are made by either syringe or cannulae.

Polymerizations are conducted in nitrogen-sparged test tubes by adding together the tungsten-imido compound and activator components (2.5 ml of each), mixing on a vortex mixer and then inserting the tube into an oil bath at 80 °C or higher or into a heated block at about 30 °C. Gel times (*t*<sub>gel</sub>) are estimated by observing the initial viscosity from the time of mixing the tungsten-imido compound and activator solutions containing DCPD until formation of a gel. Similarly, the time from mixture of the solutions until the temperature reached 100 °C (above ambient temperature) or 180 °C (above the 80 °C bath temperature) is noted and recorded as the induction time or cure time.

In addition to measuring gel and cure times and residual monomer level, a measurement of swell value is made. The swell value is an indication of the degree of crosslinking in the polymer, i.e., lower swell values indicate a higher degree of crosslinking. The general procedure used for swell value determinations is as follows: A 5 gram sample of polymer is removed from its test tube (by breaking the glass) and carefully sliced into 1-2 mm thick sections across the cylindrical axis. The burrs are removed, and each slice weighed to the nearest milligram. This is done for each sample at a given monomer feed. The samples are then placed in a volume of toluene (50 ml of toluene for each gram of polymer), heated to reflux for 16 hours (overnight) and cooled. After this time, each sample is removed from the flask and placed in a small dish of fresh toluene. The slices are removed, patted dry, and weighed individually, taking

care not to tear the swollen samples. The swell values are calculated using the following formula: swell (%) =  $(W_2 - W_1)/W_1 \times 100\%$ , where  $W_1$  = initial weight of the polyDCPD sample and  $W_2$  = weight of solvent swollen polyDCPD sample. Since the swell value is an indication of the degree of crosslinking in the polymer, low values are preferred.

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#### Example 1

A tungsten-imido compound having the formula  $W(NPh)Cl_4O(CH_2CH_3)_2$  (where "Ph" is phenyl) is prepared in the following manner. A quantity of  $WOCl_4$  (5.9 g;  $1.46 \times 10^{-2}$  moles) is placed into a 250 ml round bottomed flask together with a magnetic stir bar. To the tungsten oxytetrachloride is added octane (100 ml) and phenyl isocyanate (1.6 ml;  $1.47 \times 10^{-2}$  moles). This reaction mixture is stirred while refluxing for a number of hours under reflux. The flask is taken into the dry box where the solids are obtained by filtration and washed with a small quantity of pentane. The green powder obtained is dissolved in a minimum of diethyl ether (70 ml). The green colored solution is filtered and the resultant filtrate is kept. Removal of the solvent from the ether solution results in the deposition of large dark green blocks. To this material is added 10 ml diethyl ether so that the compound can be recovered from the flask. The solids collected by filtration are filtered and dried for a short time in vacuo. Total yield of  $W(NPh)Cl_4O(CH_2CH_3)_2$  is 5.81 grams (81%).

#### Example 2

A tungsten-imido compound having the formula  $W(NPh)(OC(CH_3)_3)_4$  is prepared in the following manner. A quantity of  $W(NPh)Cl_4O(CH_2CH_3)_2$  (3.17 g;  $6.46 \times 10^{-3}$  moles), prepared in accordance with Example 1, is placed into a 250 ml round bottomed flask containing a magnetic stir bar and the vessel is then stopped. Diethyl ether (100 ml) is added to the  $W(NPh)Cl_4O(CH_2CH_3)_2$  by cannula and the green solution cooled to 0 °C in an acetone-ice bath. A quantity of lithium tert-butoxide (2.07 g;  $25.9 \times 10^{-3}$  mol) is placed into a reaction vessel and dissolved in 100 ml of diethyl ether. The lithium tert-butoxide-diethyl ether solution is slowly cannulated into the reaction flask containing the tungsten-imido compound and the solution immediately turns pale yellow. After stirring the mixture overnight another 100 ml of diethyl ether are added to the reaction flask and the solution stirred for a short period of time to ensure all the desired compound is dissolved. The lithium chloride salt formed in the reaction is allowed to settle from solution, and the supernatant yellow liquid cannulated into another vessel. Removal of the diethyl ether yields the primrose yellow complex,  $W(NPh)(OC(CH_3)_3)_4$ . The remaining salts are taken into the dry box and washed with pentane (100 ml). This solution is filtered and the pale yellow filtrate obtained evaporated under reduced pressure to give a yellow solid. The two yellow solids obtained are combined, stirred with 30 ml of pentane, and filtered. The filtrate is transferred to a small round bottomed flask and sparged to dryness. The yield of  $W(NPh)(OC(CH_3)_3)_4$  is 3.50 grams (96%).

#### Example 3

In this example mixtures of tungsten-imido compound precursor and activator are prepared using the tungsten-imido compound of Example 1 with diethylaluminum chloride. Stock solutions of  $W(NPh)Cl_4O(CH_2CH_3)_2$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD: $W(NPh)Cl_4O(CH_2CH_3)_2$ . The ratio of DCPD:diethylaluminum chloride is 1000:3 (50 ml:1.22 ml of a 1.9 M  $(CH_3CH_2)_2AlCl$  solution in toluene). Each of the above components is prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3 (DCPD:W:activator). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. Pertinent details from the DCPD polymerizations employing  $W(NPh)Cl_4O(CH_2CH_3)_2/(CH_3CH_2)_2AlCl$  are as follows: At 30 °C,  $t_{gel}$  = 5 seconds;  $t_{100^\circ C}$  = 28 seconds;  $t_{cure}$  = 33 seconds;  $T_{max}$  = 147 °C. At 80 °C,  $t_{gel}$  = 5 seconds;  $t_{cure}$  = 29 seconds;  $T_{max}$  = 142 °C; swell (%) = 74.6; residual DCPD (%) = 18.4.

#### Example 4

In this example mixtures of tungsten-imido compound and activator are prepared using the tungsten-imido compound of Example 1 with tri-n-butyltin hydride. Stock solutions of  $W(NPh)Cl_4O(CH_2CH_3)_2$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD: $W(NPh)Cl_4O(CH_2CH_3)_2$ . The ratio of DCPD:tri-n-butyltin hydride ( $(CH_3CH_2CH_2CH_2)_3SnH$ ) is 1000:3 (50 ml:0.59 ml). Each of the above compo-

nents is prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3 (DCPD:W:activator). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. Pertinent details from the DCPD polymerizations employing  $W(NPh)Cl_4O(CH_2CH_3)_2/(CH_3CH_2CH_2CH_2)_3SnH$  are as follows: At 30 °C,  $t_{gel} = 1$  second;  $t_{100^\circ C} = 4$  seconds;  $t_{cure} = 25$  seconds;  $T_{max} = 198^\circ C$ .

#### Example 5

In this example, mixtures of tungsten-imido compound and activator are prepared using the tungsten-imido compound of Example 1 with tri-n-butyltin hydride and tributyl phosphite (TBP) as the rate moderator. Stock solutions of  $W(NPh)Cl_4O(CH_2CH_3)_2$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD:W(NPh)Cl<sub>4</sub>O(CH<sub>2</sub>CH<sub>3</sub>)<sub>2</sub>. The ratio of DCPD:tri-n-butyltin hydride:tributyl phosphite is 1000:3:3 (50 ml:0.59 ml:0.60 ml). Each of the above components is prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3:3 (DCPD:W:activator:TBP). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. Pertinent details from the DCPD polymerizations employing  $W(NPh)Cl_4O(CH_2CH_3)_2/(CH_3CH_2CH_2CH_2)_3SnH/TBP$  are as follows: At 30 °C,  $t_{gel} = 30$  seconds;  $t_{100^\circ C} = 125$  seconds;  $t_{cure} = 154$  seconds;  $T_{max} = 196^\circ C$ ; swell (%) = 151.7; residual DCPD (%) = 1.02. At 80 °C,  $t_{gel} = 14$  seconds;  $t_{100^\circ C} = 23$  seconds;  $t_{cure} = 49$  seconds;  $T_{max} = 210^\circ C$ ; swell (%) = 140.3; residual DCPD (%) = 3.23.

#### Example 6

In this example, mixtures of tungsten-imido compound and activator are prepared using the tungsten-imido compound of Example 2 with diethylaluminum chloride. Stock solutions of  $W(NPh)(OC(CH_3)_3)_4$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD:W(NPh)(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>4</sub>. The ratio of DCPD:diethylaluminum chloride is 1000:3 (50 ml:1.22 ml). The above components are prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3 (DCPD:W:activator). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. The pertinent information for the polymerizations of  $W(NPh)(OC(CH_3)_3)_4/(CH_3CH_2)_2AlCl$  is shown in the following details. At 30 °C,  $t_{gel} = 6$  seconds;  $t_{100^\circ C} = 23$  seconds;  $t_{180^\circ C} = 29$  seconds;  $t_{cure} = 44$  seconds;  $T_{max} = 202^\circ C$ ; swell (%) = 157.5; residual DCPD (%) = 0.38. At 80 °C,  $t_{gel} = 4$  seconds;  $t_{100^\circ C} = 19$  seconds;  $t_{180^\circ C} = 23$  seconds;  $t_{cure} = 39$  seconds;  $T_{max} = 210^\circ C$ ; swell (%) = 194.4; residual DCPD (%) = 0.41.

#### Example 7

In this example, mixtures of tungsten-imido compound and activator are prepared using the tungsten-imido compound of Example 2 with diethylaluminum chloride and 2,6-dimethylpyridine rate moderator. Stock solutions of  $W(NPh)(OC(CH_3)_3)_4$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD:W(NPh)(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>4</sub>. The ratio of DCPD:diethylaluminum chloride:2,6-dimethylpyridine is 1000:3:3 (50 ml:1.22 ml:0.26 ml). The above components are prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3:3 (DCPD:W:activator:rate moderator). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. The pertinent information for the polymerizations of  $W(NPh)(OC(CH_3)_3)_4/(CH_3CH_2)_2AlCl/2,6$ -dimethylpyridine is shown in the following details. At 30 °C,  $t_{gel} = 3$  seconds;  $t_{100^\circ C} = 65$  seconds;  $t_{180^\circ C} = 116$  seconds;  $t_{cure} = 129$  seconds;  $T_{max} = 191^\circ C$ ; swell (%) = 213.2; residual DCPD (%) = 0.61. At 80 °C,  $t_{gel} = 3$  seconds;  $t_{100^\circ C} = 52$  seconds;  $t_{180^\circ C} = 56$  seconds;  $t_{cure} = 69$  seconds;  $T_{max} = 215^\circ C$ ; swell (%) = 206.9; residual DCPD (%) = 0.94.

#### Example 8

In this example, mixtures of tungsten-imido compound and activator are prepared using the tungsten-imido compound of Example 2 with diethylaluminum chloride. Stock solutions of  $W(NPh)(OC(CH_3)_3)_4$  in DCPD are prepared at a ratio of 1000:1 (100 ml:0.357 g), DCPD:W(NPh)(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>4</sub>. The ratio of DCPD:diethylaluminum chloride:tributyl phosphite (TBP) is 1000:3:3 (50 ml:1.22 ml:0.60 ml). The above

components are prepared by charging a 10 oz. pop bottle. The final reaction ratio for mixed tungsten-imido and activator components is 2000:1:3:3 (DCPD:W:activator:rate moderator). Test tube polymerizations are performed by mixing 2.5 ml of each component and maintaining the temperature at room temperature or placing the test tube directly into an oil bath. The pertinent information for the polymerizations of W(NPh)-(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>4</sub>/(CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub>Al/TBP is shown in the following details: At 30 °C,  $t_{\text{gel}}$  = 95 seconds;  $t_{100^\circ\text{C}}$  = 266 seconds;  $t_{180^\circ\text{C}}$  = 306 seconds;  $t_{\text{cure}}$  = 295 seconds;  $T_{\text{max}}$  = 188 °C; swell (%) = 184.8; residual DCPD (%) = 0.69. At 80 °C,  $t_{\text{gel}}$  = 21 seconds;  $t_{100^\circ\text{C}}$  = 45 seconds;  $t_{180^\circ\text{C}}$  = 49 seconds;  $t_{\text{cure}}$  = 63 seconds;  $T_{\text{max}}$  = 215 °C; swell (%) = 177.3; residual DCPD (%) = 1.06.

#### 10 Example 9

The compound W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>) is prepared in a manner similar to the method of Examples 1 and 2. W(NPh)Cl<sub>4</sub>O(CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub> is allowed to react with the prerequisite amount of lithium 2,6-diisopropylphenoxide (LiOC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>) in diethyl ether.

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#### Example 10

The compound W(NPh)(OC<sub>6</sub>H<sub>3</sub>-2,6-Cl<sub>2</sub>)<sub>2</sub>Cl<sub>2</sub> is prepared in a manner similar to the method of Examples 1 and 2. W(NPh)Cl<sub>4</sub>O(CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub> is allowed to react with the prerequisite amount of lithium 2,6-diisopropylphenoxide (LiOC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>) in diethyl ether.

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#### Example 11

The compound W(NC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>)(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>2</sub>Cl\* tetrahydrofuran is prepared in a manner similar to the method of Examples 1 and 2. W(NPh)Cl<sub>4</sub>O(CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub> is allowed to react with the prerequisite amount of lithium tert-butoxide (LiOC(CH<sub>3</sub>)<sub>3</sub>) in tetrahydrofuran.

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#### Example 12

The tungsten-imido compound stock solution is prepared by charging a 10 oz. pop bottle with the appropriate amount of W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>) from Example 9, and DCPD. Stock solutions of the activator are prepared by charging a 10 oz. pop bottle with the appropriate amounts of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH and tributyl phosphite (TBP). The following table indicates the amounts of materials used.

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Reaction Ratio	A-Component	B-Component
DCPD:W:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP 2000:1:3:3	DCPD:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP 1000:3:3 100 ml:0.59 ml:0.60 ml	DCPD:W 1000:1 100 ml:0.51 g

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The final reaction ratio for mixed tungsten-imido and activator components is DCPD:W:(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH:TBP = 2000:1:3:3. An exothermic polymerization is observed for which the following parameters are pertinent. At 31 °C,  $t_{\text{gel}}$  = 62 seconds;  $t_{100^\circ\text{C}}$  = 147 seconds;  $t_{\text{cure}}$  = 166 seconds;  $T_{\text{max}}$  = 200 °C; swell (%) = 162.8; residual DCPD (%) = 0.19. At 80 °C,  $t_{\text{gel}}$  = 18 seconds;  $t_{100^\circ\text{C}}$  = 46 seconds;  $t_{\text{cure}}$  = 64 seconds;  $T_{\text{max}}$  = 223 °C; swell (%) = 164.0; residual DCPD (%) = 0.57.

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#### Example 13

The tungsten-imido compound stock solution is prepared by charging a 10 oz pop bottle with the appropriate amount of W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>) from Example 9 and DCPD. Stock solutions of the activator are prepared by charging a 10 oz pop bottle with the appropriate amount of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH. The following table indicates the amounts of materials used.

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Reaction Ratio	A-Component	B-Component
DCPD:W:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH 2000:1:3	DCPD:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH 1000:3 100 ml:0.59 ml	DCPD:W 1000:1 100 ml:0.51 g

The final reaction ratio for mixed tungsten-imido catalyst and activator components is from DCPD:W:-  
(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH = 2000:1:3. An exothermic polymerization is observed for which the following  
parameters are pertinent: At 31 °C,  $t_{gel}$  = 18 seconds;  $t_{100^{\circ}C}$  = 63 seconds;  $t_{cure}$  = 97 seconds;  $T_{max}$  =  
193 °C; swell (%) = 178.5; residual DCPD (%) = 0.12. At 80 °C,  $t_{gel}$  = 11 seconds;  $t_{100^{\circ}C}$  = 60 seconds;  
 $T_{max}$  = 218 °C; swell (%) = 191.0; residual DCPD (%) = 0.51.

#### Example 14

The tungsten-imido compound stock solution is prepared by charging a 10 oz. pop bottle with the  
appropriate amount of W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-Cl<sub>2</sub>)<sub>2</sub> from Example 10, DCPD, and 2-methoxyethyl ether  
(DG). Stock solutions of the activator are prepared by charging a 10 oz. pop bottle with the appropriate  
amounts of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH and tributyl phosphite (TBP). The following table indicates the amounts  
of materials used.

Reaction Ratio	A-Component	B-Component
DCPD:W:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP 2000:1:2:3:2	DCPD:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP 1000:3:2 100 ml:0.59 ml:0.40 ml	DCPD:W:DG 1000:1:2 100 ml:0.491g:0.21 ml
4000:1:2:3:2	2000:3:2 100 ml:0.30 ml:0.20 ml	2000:1:2 100 ml:0.246 g:0.11 ml
8000:1:2:3:2	4000:3:2 100 ml:0.15 ml:0.10ml	4000:1:2 100 ml:0.122g:0.05 ml

The final reaction ratio for mixed tungsten-imido and activator components is varied from DCPD:W:DG:-  
(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH:TBP = 2000:1:2:3:2 to 8000:1:2:3:2 (see Table 1).

Table 1

DCPD:W:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	Initial Temp. (°C)	$t_{gel}$ (sec)	$T_{100^{\circ}C}$ (sec)	$T_{180^{\circ}C}$ (sec)	$t_{Tmax}$ (sec)	$T_{max}$ (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	30	9	50	60	74	197	143.1	0.37
2000:1:2:3:3	80	11	17	23	37	207	159.4	0.45
4000:1:2:3:3	30	11	101	108	126	197	129.4	0.44
4000:1:2:3:3	80	11	20	27	49	209	149.5	0.77
8000:1:2:3:3	30	7	172	185	201	194	124.4	0.95
8000:1:2:3:3	80	9	24	29	44	207	149.3	2.14

#### Example 15

The tungsten-imido compound stock solution is prepared by charging a 10 oz pop bottle with the  
appropriate amount of W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-Cl<sub>2</sub>)<sub>2</sub> from Example 10, DCPD, and 2-methoxyethyl ether  
(DG). Stock solutions of the activator are prepared by charging a 10 oz pop bottle with the appropriate  
amounts of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH and TBP. The following table indicates the amounts of materials used.



Reaction Ratio	A-Component	B-Component
DCPD:W:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	DCPD:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	DCPD:W:DG
2000:1:2:3:3	1000:3:3 100 ml:0.59 ml:0.60 ml	1000:1:2 100 ml:0.59 g:0.21 ml
2000:1:2:4:3	1000:4:3 100 ml:0.79 ml:0.60 ml	1000:1:2 100 ml:0.59 g:0.21 ml
2000:1:2:8:3	1000:8:3 100 ml:1.58 ml:0.60 ml	1000:1:2 100 ml:0.59 g:0.21 ml

The final reaction ratio for mixed tungsten-imido and activator components is varied from DCPD:W:DG:-  
(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH:TBP = 2000:1:2:3:3 to 2000:1:2:8:3 (see Table 2).

Table 2

DCPD:W:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	Initial Temp. (°C)	t <sub>gd</sub> (s ec)	T <sub>100°C</sub> (s ec)	T <sub>180°C</sub> (s ec)	t <sub>Tmax</sub> (s ec)	T <sub>max</sub> (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	30	9	50	60	74	197	143.1	0.37
2000:1:2:3:3	80	11	17	23	37	207	159.4	0.45
4000:1:2:4:3	30	7	34	41	61	207	153.5	0.46
4000:1:2:4:3	80	5	14	19	32	202	191.7	0.62
8000:1:2:8:3	30	5	21	28	47	203	197.4	0.87
8000:1:2:8:3	80	5	16	22	38	202	215.6	0.88

### Example 16

The stock solution of the tungsten-imido compound is prepared by mixing the appropriate amounts of W(NPh)Cl<sub>2</sub>(OC<sub>6</sub>H<sub>3</sub>-2,6-Cl<sub>2</sub>)<sub>2</sub> from Example 10, DCPD, and 2-methoxyethyl ether (DG) in a 10 oz pop bottle. Activator stock solutions are prepared by charging a 10 oz. pop bottle with the appropriate amounts of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH and TBP. The following table indicates the amounts of materials used.

Reaction Ratio	A-Component	B-Component
DCPD:W:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	DCPD:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	DCPD:W:DG
2000:1:2:3:0	1000:3:0 100 ml:0.59 ml:0.00 ml	1000:1:2 100 ml:0.491 g:0.21 ml
2000:1:2:3:1	1000:3:2 100 ml:0.59 ml:0.40 ml	1000:1:2 100 ml:0.491 g:0.21 ml
2000:1:2:3:4	1000:3:4 100 ml:0.59 ml:0.79 ml	1000:1:2 100 ml:0.491 g:0.21 ml
2000:1:2:3:6	1000:3:6 100 ml:0.59 ml:1.19 ml	1000:1:2 100 ml:0.491 g:0.21 ml

The final reaction ratio for mixed tungsten-imido and activator components was varied from DCPD:W:DG:(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH:TBP = 2000:1:2:3:0 to 2000:1:2:3:6 (see Table 3).

Table 3

DCPD:W:DG:(CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>3</sub> SnH:TBP	Initial Temp. (°C)	t <sub>gd</sub> (sec)	T <sub>100°C</sub> (sec)	T <sub>180°C</sub> (sec)	t <sub>Tmax</sub> (sec)	T <sub>max</sub> (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:0	30	1	9	16	29	201	158.7	0.35
2000:1:2:3:0	80	1	7	16	28	207	158.7	0.27
2000:1:2:3:2	30	4	37	45	61	201	162.8	0.35
2000:1:2:3:2	80	4	13	20	34	205	161.7	0.38
2000:1:2:3:4	30	9	63	70	86	196	154.6	0.39
2000:1:2:3:4	80	13	15	18	36	215	172.8	0.48
2000:1:2:3:6	30	10	84	92	105	191	155.0	0.48
2000:1:2:3:6	80	12	15	21	40	214	173.0	0.60

Example 17

In this example dicyclopentadiene is polymerized with W(NC<sub>6</sub>H<sub>5</sub>-2,6-((CH<sub>3</sub>)<sub>2</sub>CH)<sub>2</sub>(OC(CH<sub>3</sub>)<sub>3</sub>)<sub>2</sub>Cl<sub>2</sub> THF prepared in example 11 and tri-*n*-butyltin hydride ((CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH) activator. A monomer solution containing the tungsten-imido compound is prepared as follows: 0.454 g (0.000 x 10<sup>-4</sup> mol) is placed in a nitrogen sparged and capped vessel. To this is added 100 ml of DCPD and the mixture shaken to ensure full dissolution of the tungsten-imido compound. The activator component is made similarly by the addition of a quantity of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH (0.59 ml, 2.193 mmol) to a sparged and capped pop bottle containing 100 ml of DCPD. The final reaction ratio achieved when the two components are mixed is then 2000:1:3 (DCPD:W:(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH).

Polymerization of DCPD occurs when 2.5 ml of the activator is syringed into a sparged test tube containing 2.5 ml of the catalyst precursor stock solution, the contents mixed by vortex and the tube placed in an oil bath heated to 80° C. An exothermic polymerization is observed for which the following parameters are pertinent: At 80° C, t<sub>gel</sub> = 36 seconds; t<sub>100°C</sub> = 235 seconds; t<sub>cure</sub> = 300 seconds; T<sub>max</sub> = 176° C; swell (%) = 118.1; residual DCPD (%) = 3.03.

Example 18

The procedure of Example 17 is followed except that the (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH solution is replaced by a mixture of (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH in DCPD containing three equivalents of tributyl phosphite (TBP) per tin, i.e., 0.59 ml (4.387 mmol) (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH and 0.60 ml TBP in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:(CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH:TBP is 2000:1:3:3. An exothermic polymerization is observed for which the following parameters are pertinent: At 80° C, T<sub>gel</sub> = 30 seconds; t<sub>100°C</sub> = 128 seconds; t<sub>cure</sub> = 178 seconds; T<sub>max</sub> = 197° C; swell (%) = 122.3; residual DCPD (%) = 4.18.

Example 19

The procedure of Example 17 is followed except that the (CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>)<sub>3</sub>SnH solution is replaced by a mixture of (CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub>AlCl("Al") in DCPD, i.e., 1.22 ml of a 1.8 M toluene solution of diethylaluminum chloride in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Al is 2000:1:3. An exothermic polymerization is observed for which the following parameters are pertinent: At 30° C, t<sub>gel</sub> = 17 seconds; t<sub>100°C</sub> = 39 seconds; t<sub>180°C</sub> = 42 seconds; t<sub>cure</sub> = 57 seconds; T<sub>max</sub> = 205° C; swell (%) = 127.3; residual DCPD (%) = 0.10. At 80° C, t<sub>gel</sub> = 13 seconds; t<sub>100°C</sub> = 23 seconds; t<sub>180°C</sub> = 27 seconds; T<sub>cure</sub> = 43 seconds; T<sub>max</sub> = 216° C; swell (%) = 124.4; residual DCPD (%) = 0.35.

Example 20

The procedure of Example 19 is followed except that (CH<sub>3</sub>CH<sub>2</sub>)<sub>2</sub>AlCl("Al") solution is replaced by a mixture of Al in DCPD containing three equivalents of tributyl phosphite (TBP) per aluminum, i.e., 1.22 ml of a 1.8 M toluene solution of diethylaluminum chloride and 0.60 ml TBP in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Al:TBP is 2000:1:3:3. An exothermic polymerization is observed for which the following parameters are pertinent: At 80° C, t<sub>gel</sub> = 30 seconds; t<sub>100°C</sub> = 91 seconds; t<sub>180°C</sub> = 104 seconds;

$T_{\text{cure}} = 114$  seconds;  $T_{\text{max}} = 206^{\circ}\text{C}$ ; swell(%) = 117.5; residual DCPD (%) = 1.64.

#### Example 21

The procedure of Example 17 is followed except that the  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  solution is replaced by a mixture of triethylaluminum  $((\text{CH}_3\text{CH}_2)_3\text{Al})$  ("Al") in DCPD, i.e., 1.16 ml of 1.9 M Al (in toluene) in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Al is 2000:1:3. An exothermic polymerization is observed for which the following parameters are pertinent: at  $80^{\circ}\text{C}$ ,  $t_{\text{gel}} = 49$  seconds;  $t_{100^{\circ}\text{C}} = 138$  seconds;  $t_{180^{\circ}\text{C}} = 168$  seconds;  $t_{\text{cure}} = 180$  seconds;  $T_{\text{max}} = 229^{\circ}\text{C}$ ; swell (%) = 18.6; residual DCPD (%) = 3.52.

#### Example 22

The procedure of Example 17 is followed except that the  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  solution is replaced by a mixture of diethylzinc (Zn) in DCPD, i.e., 2.00 ml of 1.1 M diethylzinc (in toluene) in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Zn is 2000:1:3. An exothermic polymerization is observed for which the following parameters are pertinent: at  $80^{\circ}\text{C}$ ,  $t_{\text{gel}} = 36$  seconds;  $t_{100^{\circ}\text{C}} = 70$  seconds;  $t_{180^{\circ}\text{C}} = 75$  seconds;  $T_{\text{cure}} = 90$  seconds;  $T_{\text{max}} = 226^{\circ}\text{C}$ ; swell (%) = 118.4; residual DCPD (%) = 1.17.

#### Example 23

The compound  $\text{W}(\text{NC}_6\text{H}_5-2,6-((\text{CH}_3)_2\text{CH})_2)\text{OCCH}_3(\text{CF}_3)_2\text{Cl}_2 \cdot \text{THF}$  is prepared in a manner similar to the method recited in Examples 1 and 2.  $\text{W}(\text{NPh})\text{Cl}_4\text{O}(\text{CH}_3\text{CH}_2)_2$  is allowed to react with the prerequisite amount of lithium hexafluoro-*tert*-butoxide ( $\text{LiOCCH}_3(\text{CF}_3)_2$ ) in tetrahydrofuran.

#### Example 24

In this example dicyclopentadiene is polymerized with the  $\text{W}(\text{NC}_6\text{H}_5-2,6-((\text{CH}_3)_2\text{CH})_2)(\text{OCCH}_3(\text{CF}_3)_2)_2\text{Cl}_2 \cdot \text{THF}$  prepared in Example 23 and tri-*n*-butyltin hydride  $((\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH})$  activator. A monomer solution containing the tungsten-imido compound is prepared as follows: 0.612g ( $0.071 \times 10^{-4}$  mol) is placed in a nitrogen sparged and capped vessel. To this is added 100 ml of DCPD and the mixture shaken to ensure full dissolution of the tungsten-imido compound. The activator component is made similarly by the addition of a quantity of  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  (0.59 ml, 2.193 mmol) to a sparged and capped pop bottle containing 100 ml of DCPD. The final reaction ratio achieved when the two components are mixed is then 2000:1:3 (DCPD:W: $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$ ).

Polymerization of DCPD occurs when 2.5 ml of the activator is syringed into a sparged test tube containing 2.5 ml of the tungsten-imido compound stock solution, the contents mixed by vortex and the tube placed in an oil bath heated to  $80^{\circ}\text{C}$ . An exothermic polymerization is observed for which the following parameters are pertinent: At  $80^{\circ}\text{C}$ ,  $t_{\text{gel}} = 32$  seconds;  $t_{100^{\circ}\text{C}} = 64$  seconds;  $t_{180^{\circ}\text{C}} = 73$  seconds;  $t_{\text{cure}} = 91$  seconds;  $T_{\text{max}} = 218^{\circ}\text{C}$ ; swell (%) = 143.2; residual DCPD (%) = 0.24.

#### Example 25

The procedure of Example 24 is followed except that the  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  ("Sn") solution is replaced by a mixture of Sn in DCPD containing three equivalents of tributyl phosphite (TBP) per Sn, i.e., 0.59 ml (4.387 mmol) Sn and 0.60 ml TBP in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Sn:TBP is 2000:1:3:3. An exothermic polymerization is observed for which the following parameters are pertinent: At  $80^{\circ}\text{C}$ ,  $t_{\text{gel}} = 67$  seconds;  $t_{100^{\circ}\text{C}} = 197$  seconds;  $t_{180^{\circ}\text{C}} = 205$  seconds;  $t_{\text{cure}} = 221$  seconds;  $T_{\text{max}} = 230^{\circ}\text{C}$ ; swell (%) = 153.5; residual DCPD (%) = 0.45.

#### Example 26

The procedure of Example 24 is followed except that the  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  solution is replaced by a mixture of  $(\text{CH}_3\text{CH}_2)_2\text{AlCl}$  ("Al") in DCPD, i.e., 1.22 ml of a 1.8 M toluene solution of diethylaluminum chloride in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Al is 2000:1:3. An exothermic polymerization is observed for which the following parameters are pertinent: At  $30^{\circ}\text{C}$ ,  $t_{\text{gel}} = 50$  seconds;  $t_{100^{\circ}\text{C}} = 127$  seconds;  $t_{180^{\circ}\text{C}} = 137$  seconds;  $t_{\text{cure}} = 150$  seconds;  $T_{\text{max}} = 199^{\circ}\text{C}$ ; swell (%) = 118.0; residual DCPD (%) = 0.40. At  $80^{\circ}\text{C}$ ,  $t_{\text{gel}} = 16$  seconds;  $t_{100^{\circ}\text{C}} = 33$  seconds;  $t_{180^{\circ}\text{C}} = 39$  seconds;  $t_{\text{cure}} = 52$  seconds;  $T_{\text{max}} = 211^{\circ}\text{C}$ ; swell (%) = 135.2; residual DCPD (%) = 0.25.

Example 27

The procedure of Example 26 is followed except that the  $(\text{CH}_3\text{CH}_2)_2\text{AlCl}$  ("Al") solution is replaced by a mixture of Al in DCPD containing three equivalents of tributyl phosphite (TBP) per aluminum, i.e., 1.22 ml of a 1.8 M toluene solution of diethylaluminum chloride and 0.60 ml TBP in 100 ml DCPD. Thus, the final reaction ratio of DCPD:W:Al:TBP is 2000:1:3:3. An exothermic polymerization is observed for which the following parameters are pertinent: At 80 °C,  $t_{\text{gel}} = 47$  seconds;  $t_{100^\circ\text{C}} = 113$  seconds;  $t_{180^\circ\text{C}} = 118$  seconds;  $t_{\text{cure}} = 131$  seconds;  $T_{\text{max}} = 241$  °C; swell (%) = 114.9; residual DCPD (%) = 0.23.

10 Example 28

The procedure of Example 24 is followed except that the  $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{SnH}$  solution is replaced by a mixture of diethylzinc ("Zn") in DCPD, (in toluene) in 100 ml DCPD.

Thus, the final reaction ratio of DCPD:W:Zn is 2000:1:3. An exothermic polymerization is observed for which the following parameters are pertinent: At 80 °C,  $t_{\text{gel}} = 33$  seconds;  $t_{100^\circ\text{C}} = 48$  seconds;  $t_{180^\circ\text{C}} = 51$  seconds;  $t_{\text{cure}} = 68$  seconds;  $T_{\text{max}} = 226$  °C; swell (%) = 321.0; residual DCPD (%) = 0.14.

Example 29

In this example, the effect of rate modification by addition of the rate modifier pyridine is determined with the tungsten-imido compound catalyst of Example 2 (i.e.,  $\text{W}(\text{NPh})(\text{OC}(\text{CH}_3)_3)_4$ ) and the diethylaluminum chloride ("Al") activator (1.8 M in toluene) in DCPD in a 10 oz. pop bottle. The solution of the tungsten-imido compound is made up to 1000:1 (DCPD:W) by dissolving 0.412g of  $\text{W}(\text{NPh})(\text{OC}(\text{CH}_3)_3)_4$  in 100 ml of DCPD. The activator solution is prepared by adding Al (1.22 ml) to 50 ml of DCPD containing 0.18 ml pyridine (py). One pyridine per Al is employed in this formulation. The overall reaction stoichiometry achieved upon mixing the two components is 2000:1:3:3 (DCPD:W:Al:py). The pertinent information for the DCPD polymerization by  $\text{W}(\text{NPh})(\text{OC}(\text{CH}_3)_3)_4/\text{Al.py}$  is shown by the following parameters. At 30 °C,  $t_{\text{gel}} = 5$  seconds;  $t_{100^\circ\text{C}} = 96$  seconds;  $t_{\text{cure}} = 140$  seconds;  $T_{\text{max}} = 199$  °C; swell (%) = 164.7; residual DCPD (%) = 0.85. At 80 °C,  $t_{\text{gel}} = 3$  seconds;  $t_{100^\circ\text{C}} = 19$  seconds;  $t_{\text{cure}} = 31$  seconds;  $T_{\text{max}} = 197$  °C; swell (%) = 196.7; residual DCPD (%) = 0.57.

**Claims**

1. A catalyst composition for the polymerization of at least one strained ring nonconjugated polycyclic cycloolefin monomer and comprising a tungsten compound and an activator, characterized in that the tungsten compound is a tungsten-imido compound having the formula  $\text{W}(\text{NR}^1)\text{X}_{4-x}(\text{OR}^2)_x \cdot \text{L}_y$  wherein x is 0, 1, 2, 3 or 4; y is 0 or 1;  $\text{R}^1$  and  $\text{R}^2$  are selected from alkyl, phenyl, phenyl-substituted phenyl, phenylalkyl and halogen-substituted derivatives of alkyl, phenyl, phenyl-substituted phenyl and phenylalkyl groups; X is Br or Cl and L is a donor ligand; said alkyl groups contain 1 to 8 carbon atoms; said phenyl-substituted phenyl groups contain 12 to 18 carbon atoms and said phenylalkyl groups contain 7-20 carbon atoms.
2. The catalyst composition of claim 1, further characterized in that the donor ligand is selected from diethyl ether, ethylene glycol dimethyl ether, triethylene glycol dimethyl ether, 2-methoxyethyl ether, tetraethylene glycol dimethyl ether, tetrahydrofuran, acetonitrile, benzonitrile, pyridine, pyrazine and quinuclidine.
3. The catalyst composition of claims 1 or 2, further characterized by at least one Lewis base stabilizer compound.
4. The catalyst composition of claim 3, further characterized in that the stabilizer is selected from diethyl ether, ethylene glycol dimethyl ether, 2-methoxyethyl ether, triethylene glycol dimethyl ether, tetraethylene glycol dimethyl ether, benzonitrile, acetonitrile, tetrahydrofuran, monophenols, bisphenols, polyphenols and the butylated reaction product of p-cresol and dicyclopentadiene and mixtures thereof.
5. The catalyst composition of any of the preceding claims, further characterized by at least one rate moderator selected from pyridine, pyrazine, tributyl phosphite, triethylphosphine, tributylphosphine, tricyclohexylphosphine, triphenylphosphine, methyldiphenylphosphine, dimethylphenylphosphine, tri-

ethyl phosphite, triisopropyl phosphite, ethyldiphenyl phosphonite, triphenyl phosphite, triisopropylphosphine, trimethyl phosphite, tri-tert-butylphosphine, diethylphenyl phosphonite, and tribenzylphosphine.

- 5 6. The catalyst composition of any of the preceding claims, further characterized in that the activator is tri-n-butyltin hydride.
7. The catalyst composition of any of the preceding claims, further characterized in that the activator is trioctyltin hydride.
- 10 8. The catalyst composition of any of the preceding claims, further characterized in that the tungsten-imido compound has the formula  $W(NPh)(OC_6H_3-2,6-Cl_2)_2Cl_2$ .
- 15 9. The catalyst composition of any of the preceding claims, further characterized in that the tungsten-imido compound has the formula  $W(NPh)(OC(CH_3)_3)_4$ .
10. Use of the catalyst composition of any of the preceding claims for the metathesis polymerization of at least one strained ring, nonconjugated polycyclic cycloolefin.
- 20 11. Use of the catalyst composition of claims 1 to 9 for the metathesis polymerization of at least one strained ring nonconjugated polycyclic cycloolefin characterized in that the cycloolefin is selected from dicyclopentadiene, trimers of cyclopentadiene, higher order cyclopentadiene oligomers, norbornene, norbornadiene, 4-alkylidene norbornenes, dimethanohexahydronaphthalene, dimethanooctahydronaphthalene, and alkyl-substituted derivatives of said cycloolefins and mixtures thereof.
- 25 12. Use of the catalyst composition of claims 1 to 9 for the metathesis polymerization of at least one strained ring nonconjugated polycyclic cycloolefin characterized in that the cycloolefin to tungsten-imido compound ratio is from 500:1 to 15,000:1 and the ratio of tungsten-imido compound to activator is from 1:1 to 1:8 on a molar basis.

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## EUROPEAN SEARCH REPORT

Application Number

EP 92 11 6252

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A,D	Journ. Am. Chem. Soc. 1986, 108, pp 2771-2773. "A well-characterized, highly ..." Schaverien et al *whole document*	1	C08G61/08
A,D	J. Am. Chem. Soc. 1988, 110, pp 1423-1435 "Preparation and reactivity of ..." Schrock et al *abstract*	1	
A	EP-A-0 303 969 (GOODRICH) * page 5, line 5 - line 10 *	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			C08G
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 07 DECEMBER 1992	Examiner LENTZ J.C.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	